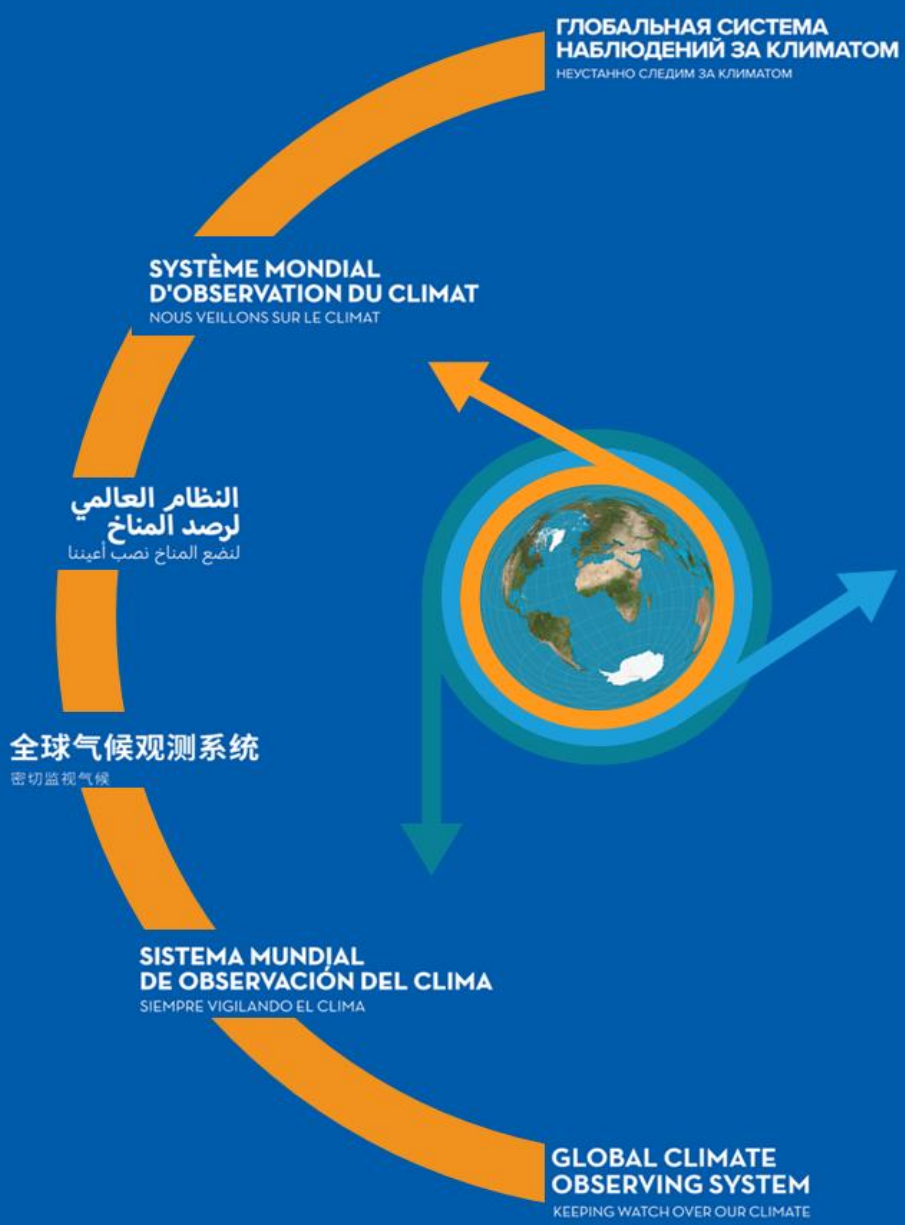
The 2022 GCOS Implementation Plan

National and Funding Agencies Supplement



GCOS

GLOBAL CLIMATE OBSERVING SYSTEM
KEEPING WATCH OVER OUR CLIMATE

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1. INTRODUCTION

This National and Funding Agencies Supplement to the 2022 GCOS Implementation Plan extracts those activities for which these agencies have been identified as key implementing partners.

The 2022 GCOS Implementation Plan (GCOS-244) is the latest in a series of implementation plans produced by GCOS since its inception in 1992. It provides a set of high priority actions which if undertaken will improve global observations of the climate system and our understanding of how it is changing. The 2022 GCOS ECVs Requirements (GCOS-245) provides revised requirements for the ECVs.

This plan aims at identifying the major practical actions that should be undertaken in the next 5-10 years. It identifies six major themes that should be addressed. Within each theme, several actions are identified.

This supplement only lists those actions within each theme that are targeted at the National agencies and the Funding agencies. Within each action the specific activities for the National and Funding agencies are highlighted in bold. In the list of implementers, those in bold are considered to take the lead in addressing and monitoring the activities.

For actions that should be performed by other actors, details can be found in the main report. This supplement is complemented by other supplements aimed at specific communities.

Acronyms, references and a list of contributors can be found in the main report GCOS-244.

Table 1. Actions for National and Funding Agencies

Theme	Actions	National Agencies	Funding Agencies
A: ENSURING SUSTAINABILITY	A1. Ensure necessary levels of long-term funding support for in situ networks, from observations to data delivery		x
B: FILLING DATA GAPS	B1. Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)		x
	B4. Expand surface and in situ monitoring of trace gas composition and aerosol properties	x	x
	B6. Expand and build a fully integrated global ocean observing system	x	
	B8. Coordinate observations and data product development for ocean CO_2 and N_2O	x	
	B10. Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles		x
D: MANAGING DATA	D2. Ensure Global Data Centres exist for all in situ observations of ECVs	x	x
	D3. Improving discovery and access to data and metadata in Global Data Centres		x
	D5. Undertake additional in situ data rescue activities		x
E: ENGAGING WITH COUNTRIES	E3. Enhance support to national climate observations		x
F: OTHER EMERGING NEEDS	F4. Improve climate monitoring of urban areas	x	
	F5. Develop an Integrated Operational Global GHG Monitoring System	x	

2. THEME A: ENSURING SUSTAINABILITY

Long-term, continuous, in situ[1] and satellite observations of the climate are necessary to understand and respond to the changing climate.

Sustained funding is essential to ensure the continuity and the expansion needed for many in situ observations of ECVs. While many atmospheric observations have sustained long-term funding, most ocean and terrestrial observations are supported through short-term funding, with a typical lifetime of a few years, leaving the development of long-term records extremely vulnerable. This is particularly true for parameters that are not traditionally monitored for weather predictions and will not be supported by WMO's GBON and SOFF, in its present design.

Since these observations are executed by a large range of actors, an effective observing system may benefit from an improved international coordination across networks and programs. Here the potential of "economy of scales" could make procurements of instruments less expensive. Sustainable networks need sustained funding and support that covers training, capacity building, equipment maintenance and replacement. Partnerships between experienced and less experienced actors provide this support.

While satellite observations have been a major success in monitoring many ECVs, long-term continuity of some satellite observations is not assured. While new satellites incorporate innovations and improvements, it is essential that consistent time-series are available across many missions. While making best efforts to ensure continuity and/or cross-referencing of key climate data sets, satellite agencies are encouraged to proceed with the exploration and demonstration of new technologies to observe the Earth system from space (e.g. Stephens et al., 2020[2]).

Future climate observing capabilities that are at risk are identified in the 2021 GCOS Status Report. This theme focuses on those in situ and satellite observations that are particularly at risk, while acknowledging that all observations of ECVs need to be sustained.

Action A1: Ensure necessary levels of long-term funding support for in situ networks, from observations to data delivery	
Activities	**1. Undertake an assessment of current levels of funding support for global in situ networks delivering relevant in situ ECV data, including cal/val measurements, and identify those in situ networks with immediate or short-term problems around adequacy and sustainability of funding - by end of 2023.** **2. Identify entities that can provide support for the networks identified as at risk in Activity 1.** **3. Advocate with funding agencies to support identified networks.**
Issue/Benefits	Not all in situ networks have the assurance of the long-term support needed to ensure the continuity and development of long-term time-series needed for climate monitoring. Although progress has been made, some networks are still supported by short- and fixed-term funding or have inadequate funding support. This action aims at making progress in addressing this issue by improving the sustainability of in situ measurement programs.

[1] In this document we refer to all non-satellite observations as "in situ" including ground-based and aircraft-based remote sensing.
[2] Stephens, G., et al., 2020: Revolution in Earth Observations. *Bulletin of the American Meteorological Society* 101, 3, E274-E285, doi.org/10.1175/BAMS-D-19-0146.1

	Improved funding support for networks performing measurements of ECVs would improve our ability to undertake long-term monitoring of the changing climate system. This informs climate assessments such as IPCC and WMO annual reports. Furthermore, it is essential for climate services, adaptation activities and mitigation efforts. Sustained in situ observations provide critical input to reanalyses and aid satellite cal/val activities, especially as new missions/instruments are launched.
Implementers	From 1 to 3: **GCOS**, WMO, NMHSs, Research organizations, Academia, Funding agencies.
Means of Assessing Progress	1. Initial inventory of the funding profile for identified in situ networks that provide ECVs, considering adequacy and sustainability of funding support. Findings are to be prepared by all GCOS panels and consolidated in the form of a GCOS report by the end of 2023. The report should provide a current health snapshot of financial support for the networks. 2. Regularly reassess and report in future GCOS Status Reports progress towards sustainable funding for those networks designated in the initial report as inadequate or at risk. 3. Number of in situ networks for which funding support as a whole has been improved.
Additional Details	GCOS panels should inventory key current in situ networks and ascertain their levels of support, and barriers to their full implementation, and highlight examples of existing sustainable solutions. NMHSs, research performing organizations and other public and private funders should then take the outcomes of these assessments and attempt to remedy issues raised. A final assessment will then be made at the end of the IP / Status report cycle.
Links with other IP Actions	All ECV need sustained support, but this GCOS IP has identified the following actions: B4: in situ observations of atmospheric composition ECVs. B6 and B7: expansion and integration of the global ocean observing system, including observations of biogeochemical/biological parameters.

3. THEME B: FILLING DATA GAPS

This theme addresses gaps in the existing observing system identified in the 2021 GCOS Status Report (GCOS-240).

By and large the observations fulfil many requirements and provide the basis for the very useful sets of ECVs. However, in situ observations for almost all the ECVs are consistently deficient over certain regions, most notably parts of Africa, South America, Southeast Asia, in the deep ocean and polar regions, a situation that has not improved since the 2015 GCOS Status Report (GCOS-195).

Reference quality observations respond to the need for monitoring the changes that are occurring in the climate system and ensure greater confidence in the assessment of future climate change and variability. They support also timely political decisions for adaptation and can help to monitor and quantify the effectiveness of internationally agreed mitigation steps. Reference quality measurement programs have already been established for different domains, however there are still gaps that need to be addressed. For surface meteorological and terrestrial networks there is currently no global and coordinated reference observing tier. Existing national reference observations are not coordinated internationally, and do not provide coordinated data access.

WMO has adopted the concept for a Global Basic Observing Network (GBON) and for the Systematic Observations Financing Facility (SOFF). If their implementation is successful, GBON will provide essential observations for global Numerical Weather Prediction (NWP) and reanalyses, covering some ECVs, and SOFF will provide targeted financial and technical support for the implementation and operation of GBON and will address some of the gaps identified in the 2021 GCOS Status Report.

Action B1: Development of reference networks (in situ and satellite Fiducial Reference Measurement (FRM) programs)	
Activities	1. Continue development of GRUAN. 2. Implement the GSRN. **3. Better align the satellite FRM program to the reference tier of tiered networks and enhance / expand FRM to fill gaps in satellite cal/val.** 4. Develop further the concept of a reference network tier across all earth observation domains. 5. Establish a long-term space-based reference calibration system to enhance the quality and traceability of earth observations. The following measurables are to be considered: high-resolution spectral radiances in the reflected solar (RS) and infrared (IR) wave bands, as well as GNSS radio occultations.
Issue/Benefits	The principal benefits of reference quality networks / measurements are: • Well characterised measurement series that are traceable to SI and/or community standards with robustly quantified uncertainties that can be used with confidence. • Improved instrument performance that transfers down to other broader global regional and national networks. • Characterisation of wider networks, especially of measurement quality. • Robust calibration/validation of satellite data. • Improved process understanding and model validation. However: • Although GRUAN has been successfully implemented since 2005, it remains far from being globally well distributed. • There is no Global Surface Reference Network, as yet. • The FRM programs of satellite agencies have been carried out independent of broader concerns around tiered network design, yet these measurements should be sustained as part of reference networks and not be funded or considered separately from broader observational strategies. There is also a need to undertake additional FRM measurements to fill critical cal/val capability gaps for some ECVs. • Whilst several in situ networks are considered to be of reference quality, as yet, apart from GRUAN, there are no additional GCOS recognized global reference networks. • Enabling traceable Earth observations from satellites will improve the accuracy and quality of many ECV data sets. In addition to meeting crucial inter-calibration needs, this effort will aid in better understanding climate relevant processes and their spectral signatures.
Implementers	1. **Lead Centre (DWD),** GCOS, WMO, NMHS. 2. **GCOS**, Lead Centre (CMA), WMO, NMHS. 3. **Space agencies**, WMO, GCOS, Funding agencies.

	4. **GCOS**, WMO, NMHS, Research organizations. 5. **Space agencies.**
Means of Assessing Progress	1. Number of certified GRUAN stations and geographical distribution of stations; number of data products; data usage measured through citations. 2. Operational GSRN (for an initial set of stations focusing on temperature and precipitation). 3. a) Alignment of FRM programs into the tiered network of networks concept; b) Additional FRM measurements to fill gaps to support satellite cal/val of ECVs such as Above Ground Biomass, albedo, FAPAR, LAI and burned area. 4. Inventory of (potential for) global reference networks across atmosphere, ocean and terrestrial. 5. Implementation of CLARREO pathfinder, TRUTHS and Prefire. Plans for long-term follow-on missions to the short-term (~1 year) pathfinder missions (CLARREO and Prefire) and long-term continuous measurements.
Additional Details	Reference-quality measurements must be traceable to SI or community recognized standards and have their uncertainties fully quantified following the guidance laid out by BIPM. Measurements across a reference network must be metrologically comparable. 1. GRUAN is envisaged as a global network of eventually 30-40 measurement sites. As of August 2021, GRUAN comprises 30 sites, 12 of which have been officially certified. However, few GRUAN stations exist in several geographical regions (e.g. Africa, South America). There is also substantial work required to expand the number of GRUAN Data Products including from a range of ground-based remote sensing and in situ balloon-borne techniques. The WG-GRUAN is supported by, and reports to, AOPC who should continue to oversee progress. Regular Implementation and Coordination Meetings should continue. Efforts should be made to better integrate GRUAN into WIGOS operations. 2. A task team has been created under GCOS and SC-ON / SC-MINT to work towards the implementation of the GSRN. The GSRN should measure both near-surface atmospheric ECVs and site-relevant terrestrial ECVs and therefore the network will be overseen jointly by AOPC and TOPC from GCOS. CMA has agreed to host the Lead Centre for the GSRN. The GSRN TT, together with CMA, is expected to develop a proposal for the initial composition of the GSRN and start operations for the selected pilot stations by 2024. 3. Integration of FRM program measurements and associated support into long-term reference quality observing programs and networks assuring long-term cal/val operations. Including the provision of new FRM measurement programs and supporting infrastructure to fill critical current gaps in ECV satellite cal/val such as: • Networks in high and low above-ground biomass regions; • Ground-based in situ measurements of above-ground biomass and vegetation dynamics following FRM protocols (Dunanson et al., 2021); • Ground-based time-series in situ measurements of surface albedo, FAPAR and LAI with their uncertainties; • An open-access network of sites for burned area products. 4. There are known networks and activities that produce reference quality measurements, i.e. BSRN, GAW networks. Efforts should be made to better recognize these as global reference networks. The panels will plan how to implement other reference networks across all domains.

	5. Spearheading spectral RS and IR measurements are the following space missions: CLARREO pathfinder will measure spectral (350 – 2300 nm) radiances and reflectances in the visible and near-IR (NASA; launch in 2023); Prefire will measure spectral (5-45 μm) far-IR emissivity (NASA; launch in 2022); Forum will measure spectral far-IR outgoing radiation (ESA; launch in 2026); and TRUTHS will measure spectral RS (ESA; launch in 2029). It is essential that Space agencies consider long-term follow-on missions to the short-term pathfinder missions (CLARREO and Prefire). This should draw upon GSICS.
Links with other IP Actions	C2: Improvements to satellite data processing depends on the availability of reference observations. D4: Improve access to co-located satellite and reference quality in situ observations.

Action B4: Expand surface and in situ monitoring of trace gas composition and aerosol properties	
Activities	**1. Expand surface-based and in situ observations of a range of atmospheric and oceanic composition ECVs, including GHGs, ozone, aerosol, clouds and water vapour, and other gaseous precursors, in the atmosphere.** **2. Promote cooperation of the existing networks for establishing new composition observing capabilities in areas where they are lacking over land (in large areas of Africa, South America, Southeast Asia), over oceans, and over ice-covered regions.**
Issue/Benefits	Well-functioning networks monitoring atmospheric composition of ECVs are beneficial for: i) evaluating the effectiveness of policies on agreed emission reductions; ii) monitoring trends and variability of atmospheric composition; iii) detecting early warning signals for climate system feedbacks on natural emissions; iv) providing real-time information in case of atmospheric hazards (e.g. biomass burning, dust events, volcanic eruptions); v) providing information for radiative forcing evaluation in global/regional climate-chemistry models; vi) evaluating global forecasting systems and atmospheric composition reanalysis using independent observations. While observations of atmospheric composition variables have further improved in the past decade thanks to new in situ observations from the ground and from commercial aircraft, surface-based and in situ networks for monitoring composition ECVs still suffers from important weaknesses: • Long-term continuity of some observations is not assured due to lack of sustained funding. • There are still important gaps in the global coverage of in situ composition observations.
Implementers	From 1 to 2: **NMHS,** Research organizations, Funding agencies, National agencies.
Means of Assessing Progress	1. Number of traceable composition observation data available from areas where they are current gaps, including remote locations. 2. Expansion of current composition networks (number of sampling stations) in areas not covered by observations.

Additional Details	Sustained composition observation capabilities both at the surface and of column characteristics of a range of trace gases, including well mixed GHGs, ozone, ozone precursors and water vapour, and aerosol with global coverage are needed. Existing capabilities need to be maintained, coordinated, and expanded to meet GCOS requirements. These include observations performed in situ (near-surface and onboard drones, aircrafts, ships, balloons and other vectors) and using remote sensing (e.g. lidar, FTIR, Brewer-Dobson). Integration needs to be sought with novel approaches to satellite measurements. In order to achieve activities 1) and 2), the following needs to be addressed: • Ensure the benefits of in situ composition observations in terms of future climate services are clearly understood by relevant national and regional authorities. • Design an implementation plan including network design and commence implementation. • Staff training.
Links with other IP Actions	A1: Expansion of atmospheric composition observations requires sustained funding. B2: Expansion of GBON could lead to more atmospheric composition observations. F4: Improve climate monitoring of urban areas will include atmospheric composition ECVs. F5: Activity 1: Design and start to implement a comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations.

Action B6: Expand and build a fully integrated global ocean observing system	
Activities	**Increase the measurements of ocean ECVs into the deep ocean, under the ice and marginal seas by improving:** **1. The Core Argo (ensuring that the target density is met), biogeochemical (BGC) and Deep Argo to achieve the OneArgo design.** **2. The ship-based hydrography, fixed-point observations, autonomous and uncrewed observations.** **3. The integration of observing networks to respond adequately to ECVs requirements.**
Issue/Benefits	There are critical sampling gaps that limit the monitoring of the ocean state (for example, heat storage, carbon cycle and impacts on the biosphere). The transformation of the current Argo array to the integrated "OneArgo" array, the deployment of repeated hydrography, the deployment of fixed-point and other autonomous observing platforms and their integration aims at addressing these gaps by providing observations of surface and subsurface ocean properties, physical, biogeochemical, and optical properties aiming to collect ocean ECVs with an improved and very much needed global coverage. The extended in situ network will be key in closing budgets for climate cycles assessments, monitoring the state of the ocean, evaluating climate risks and impacts and guiding adaptation policies. It will be essential for calibration and validation of satellite measurements. An enhanced coverage for the ocean in situ surface and subsurface ECVs is also key for improving seamless forecasts as well as contributing to meeting the goals of the Paris Agreement.
Implementers	From 1 to 3: **GOOS**, Research Agencies, Academia, National agencies (oceanographic Institutes), Space agencies, NMHS (*see also key programmes and networks in* "Additional details").

Means of Assessing Progress	1. Number of core floats deployed to maintain the target density in the global ocean including marginal seas and polar regions; and number of Deep and BGC Argo floats operating after 5 years. 2. Increase of coverage in the global ocean of ship-based hydrography and fixed-point observations, including polar areas and marginal seas after 5 years. 3. Availability of integrated products.
Additional Details	In 2020, the Argo Steering Team endorsed a new Argo array design (called "OneArgo") that is truly global (including marginal seas and under ice), full depth, and multi-disciplinary, including Core, Deep, and biogeochemical BGC Argo floats. The estimated budget of OneArgo represents a three-fold increase in cost. OneArgo will include a novel data management system with real-time data freely shared through the GTS/WIS and high-quality datasets delivered within 12 months, supporting climate-relevant assessments, inventories, and metrics. Since 2021, OneArgo is a project endorsed by the UN Ocean Decade. Ship-based hydrography and fixed-point observations, autonomous and uncrewed are essential and complementary to Argo and further efforts must be undertaken to realise the vision of a fully integrated Ocean Observing System[3]. Some of the key programs and networks contributing to this Action are GO-SHIP, OceanSITES, Ocean Color satellites, Deep Argo, Biogeochemical Argo and Global Alliance of Continuous Plankton Recorder Surveys (GACS) (see OceanOPS Report Card[4] for more details).
Links with other IP Actions	B7 and B8: Improve components of the global ocean observing system. B9: Improve estimates of latent and sensible heat fluxes and wind stress. F3: Expand global ocean climate in situ observations into EEZ and coastal zones.

Action B8: Coordinate observations and data product development for ocean CO_2 and N_2O	
Activities	**1. Develop a strategy and implementation plan to operationalize the data production and delivery of surface ocean CO_2 information.** **2. Coordinate the existing nitrous oxide (N_2O) ocean observations into a harmonised network.**
Issue/Benefits	Parties to the UNFCCC, in its Paris Agreement, have committed to conserving and enhancing sinks and reservoirs of greenhouse gases, such as CO_2 and N_2O, including oceans and coastal and marine ecosystems. As part of the Global Stocktake exercise, it will be necessary to quantify and assess both carbon emissions and natural sinks. There are already considerable national and regional efforts contributing to monitor CO_2 and N_2O in the ocean, but most of them rely on short-term research projects. A more sustained funding and better coordination will result in a better estimation of the oceanic CO_2 and N_2O emissions, an optimisation of resources of Member States and better compliance with UN agreements.
Implementers	From 1 to 2: **GOOS**, WMO, Research organizations, National agencies (*see also key programmes and networks in* "Additional details").
Means of Assessing Progress	1. Internationally agreed strategy and implementation plan that can be used by governments for funding decisions that enable integration of individual pilot elements to achieve the required global system. 2.

[3] Révelard et al., 2022: Ocean Integration: The Needs and Challenges of Effective Coordination Within the Ocean Observing System. *Frontiers in Marine Science.* https://doi.org/10.3389/fmars.2021.737671
[4] OceanOPS Report Card 2021 (ocean-ops.org)

	a) Annually published sets of harmonised global N_2O concentration and emission fields data products; b) Initiated coordinated observing network of N_2O observations.
Additional Details	1. While all of the required elements of a surface ocean CO_2 monitoring system exist (observations, data quality control and synthesis, gap-filling protocols, and projection capability) individually, there is currently no internationally-agreed strategy that coordinates national and regional efforts and expands the global network to better quantify carbon sources and sinks. In recent years, serious gaps have developed in surface CO_2 data coverage owing to funding cuts in some key underway CO_2 programmes that had been operating for decades supported by 3-4-year funding horizons based on research proposals. These programmes, and the international ocean and climate science communities they serve, suffer from the lack of an internationally agreed strategy that recognizes individual programmes as essential elements in a coordinated global network. In fact, all the elements of this monitoring system rely on individual research proposals and voluntary contributions and as such lack any long-term perspective. The development of an internationally agreed strategy for a global surface CO_2 monitoring network, with a focus on the open ocean and marginal seas, will allow Member States to identify priority observing system investments to meet data needs, further develop the foundations of a sustainable surface ocean carbon monitoring system, and respond to international and intergovernmental policy drivers and commitments to UN agreements. The key programs and networks are: WMO Global Atmospheric Watch (GAW), International Ocean Carbon Coordination Project (IOCCP), Surface Ocean CO_2 reference Observing NETwork (SOCONET), Integrated Carbon Observation System-Ocean Thematic Centre (ICOS-OTC), Surface Ocean CO_2 Atlas (SOCAT), Surface Ocean CO_2 Mapping intercomparison initiative (SOCOM), Global Carbon Project (GCP), Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP), Global Data Analysis Project (GLODAP), Biogeochemical Argo. 2. To reduce uncertainties in oceanic N_2O emission estimates and to characterise the spatial and temporal variability in N_2O distributions in a changing ocean, the establishment of a harmonised N_2O Observation Network (N_2O-ON) combining discrete and continuous data from various platforms is needed. The network will integrate observations obtained by calibrated techniques, using time-series measurements at fixed stations and repeated hydrographic sections on voluntary observing ships and research vessels. As a greenhouse gas, N_2O is involved in tropospheric warming and stratospheric ozone depletion, with estimates of the global ocean contribution to N_2O emissions ranging from 10-53%. It is important to monitor how oceanic N_2O cycling and emissions to the atmosphere are affected by observed changes in the marine environment due to warming, deoxygenation and acidification. Therefore, new N_2O data products issued annually will include a harmonised global N_2O concentration and emission fields to inform the global research community and policy makers on the status and projections of future oceanic N_2O emissions. The key programs and networks are: N_2O GO-SHIP, Ship-Of-Opportunity Programme (SOOP), MarinE MethanE and NiTrous Oxide (MEMENTO).
Links with other IP Actions	Together with B8, B6 and B7 target different aspects and components of global and integrated ocean observing system recognizing its essential role in the climate system.

Action B10: Identify gaps in the climate observing system to monitor the global energy, water and carbon cycles	
Activities	**1. Continue to periodically review observations of the Earth's energy, water, carbon cycles to identify gaps and areas of high uncertainty.** **2. Review consistency of the underlying observations.** **3. Develop plans to address the gaps identified in (1), if feasible.**
Issue/Benefits	This action will implement an objective approach to identifying gaps and major uncertainties in the global climate monitoring system. The energy, water and carbon cycles and their closure/imbalance are fundamental to understanding current climate state and change, and improved observations of the cycles will lead to improved climate projections and reduced model biases.
Implementers	From 1 to 3: **GCOS,** Research organizations, Funding agencies, WCRP.
Means of Assessing Progress	1. a) Periodic assessments of each cycle and its components at least as part of the Status Report (about every five years); b) Periodic reviews of suitability of existing ECV structure to monitor energy, water and carbon cycles at least as part of the Status Report. 2. Periodic assessment of consistency of the underlying ECVs. 3. Include plan to address the main issues for the next GCOS Implementation Plan.
Additional Details	GCOS has reviewed how well the existing structure of ECVs monitors these cycles and their components. This has revealed significant gaps in observations and highlighted areas of highest uncertainty – this information will be used to guide developments and improvements to the observing system. Expert teams reviewing observations of the cycles will report on gaps and major uncertainties for inclusion in the next GCOS Status Report. They will develop plans to address these issues in subsequent Implementation Plans. See also Section 2.4 in this GCOS IP for more details and references.
Links with other IP Actions	This action indirectly links with many others but in particular with: B3: Better EEI measurements. B4: In situ GHG observations. B8: Coordinate observations and data product development for ocean CO_2. C5: Activity 2 (estimation of aboveground biomass).

4. THEME D: MANAGING DATA

To address and understand climate change, the longest possible time series need to be preserved in perpetuity. Every ECV needs to have a recognized global data repository and where there is one, it should be complete, adequately supported and funded. Data should be stored in well-curated, open and freely available, sustainable archives with clear guidance for data centres and users. Clearly defined principles such as the TRUST Principles (Lin et al., 2020)[5] and FAIR Principles (Wilkinson et al., 2016[6]) are needed. Data rescue from hard copy or archaic digital formats allows data series to be extended in the past and needs to be adequately planned and funded with the results openly and freely available. Sustained support to these activities is

[5] Lin, D., J. Crabtree, I. Dillo, et al., 2020: The TRUST Principles for digital repositories. Sci Data 7, 144, DOI:10.1038/s41597-020-0486-7

[6] Wilkinson, M.D., et al., 2016: The FAIR guiding principles for scientific data management and stewardship. Scientific Data, 3, DOI:10.1038/sdata.2016.18

required. This theme aims at organizing more efficiently data rescue, data sharing, data curation and data provision.

Action D2: Ensure Global Climate Data Centres exist for all in situ observations of ECVs	
Activities	**1. Identify ECVs for which adequate global centres do not exist or are insufficiently supported and facilitate and support the creation or improvement of global data centres for these ECVs.** **2. Promote regional data centres, their interoperability, where possible, synchronisation of their data holdings, and the provision of data in their archives to global data centres.**
Issue/Benefits	The aim of this action is to ensure that all available observations for each ECV/ observation type are distributed from integrative data centres that meet the requirements established in Action D1. Data centres do not exist for every ECV and the continued existence of some of those that do exist is not assured due to the lack of long-term funding. This action addresses this issue and targets specifically in situ data.
Implementers	From 1 to 2: **GCOS**, WMO, GOOS, NMHS, National agencies, Funding agencies.
Means of Assessing Progress	1. a) List of climate data centres, identifying those in need of additional support followed by annual reports by GCOS panels on data centres at risk; b) List of ECVs for which no data centre exists, followed by annual updates on progress towards filling the identified gaps. 2. Establishment of a functional network of regional data centres for all ECVs of relevance in the region and their synchronisation with global data centres.
Additional Details	1. Global Climate Data Centres need to maintain and construct long-term time series of ECV data and to archive and disseminate these time series for the long term, at least several decades following the requirements established as part of Action D1. The maintenance of these data centres requires long-term assured funding. The first step is to identify all existing data centres and the status of their funding. ECVs for which data centres are missing need to be identified, and the relevant GCOS panels should advocate for the establishment of the missing centres. GCOS should also make a clear case for adequate funding of data centres and the benefits that will accrue. For example, sustained funding is urgently needed for the Global Ocean Data Analysis Project (GLODAP), where ocean biogeochemistry data is collected and stored. Despite a recent increase in the quantity of these observations GLODAP is a largely unfunded community effort. Such a situation is unsustainable, and there is a significant risk that the effort will diminish or disappear in the next few years. Following an initial assessment of adequacy, it is necessary to continuously review the health of the network of global data centres. GCOS panels should annually review the status of global data centres within their domain and highlight any issues so that these can be remedied. 2. The Global data centres are part of a network of data centres that include regional data centres and in some cases the observation networks. These need to be integrated into a global system to improve data exchange and data availability. They should also follow the requirements developed in Action D1. Sustainable funding of regional data centres and observation networks is key.

	Working with Regional Associations and Regional WIGOS Centres, GCOS should advocate for regional level data collection and curation which may then be passed on to the extent possible for inclusion in global data centre collections. This action focuses on in situ data. Information about satellite-based climate data records can be found in the ECV inventory.
Links with other IP Actions	Action D1, D2 and D3 are interconnected and pursue a common goal of preserving and providing access to ECV data in Global Data Centres.

Action D3: Improving discovery and access to data and metadata in Global Climate Data Centres	
Activities	**1. Support the creation of improved systems for accessing global archives of ECVs and facilitating their interoperability.** **2. Support the development and maintenance of software tools that assist users in discovering and accessing publicly available data sets.** **3. Facilitate access to field campaign data, where available and relevant, to improve understanding of fundamental processes.**
Issue/Benefits	Presently data are often held in ECV-specific or time-aggregation specific repositories, often without regional or global coordination and in a broad variety of formats and access protocols. This makes accessing data laborious. Sometimes, related data needs to be integrated into global collections with multiple ECVs collated together to enable data fusion. Global climate databases must be able to provide easy discovery and access of data to all potential users, maximising the utility of the data.
Implementers	From 1 to 3: **Global Data Centres**, GCOS, Funding agencies.
Means of Assessing Progress	1. Increased number of users of integrated data holdings. 2. Increased availability of open-source software tools for accessing data in common data formats. 3. Increased number of traceable field campaign data available in global archives.
Additional Details	1. GCOS should support this action by identifying organizations, data centres, and other groups interested in participating in the creation of relevant software and databases and by advocating for relevant funding opportunities to be created by funding agencies. GCOS should also communicate appropriate standards on data management, such as those developed and/or referenced in Action D1, to funding agencies and funded organizations. 2. Governments, non-governmental organizations, and funding agencies should support the development and maintenance of software tools that assist users in utilising publicly available data sets. GCOS should support this activity by communicating standards for such software, e.g., data formats to be supported, functions to be included. 3. Access to campaign field data, in particular those used for instrument intercalibration and validation, is very important to improve the traceability and thus the quality of many ECV datasets.
Links with other IP Actions	Action D1, D2 and D3 are interconnected and pursue a common goal of preserving and providing access to ECV data in Global Data Centres.

Action D5: Undertake additional in situ data rescue activities	
Activities	**1. Augment existing archives as inventoried by the WMO DARE initiative (https://community.wmo.int/data-rescue-projects-and-initiatives-dare) and the ACRE project (http://met-acre.net/) with newly discovered or as yet un-inventoried holdings available for potential rescue.** **2. Continue efforts to advance the rescue of key historical data records from hard copy or image form via an appropriate combination of professional, citizen science and class-based activities.** **3. Maintain and update data rescue best practice guidelines as detailed at e.g. https://datarescue.climate.copernicus.eu/tools-community-support.**
Issue/Benefits	The coverage of historical observations is uneven across space, time, and for different parameters. While some of these differences are due to differences in the volume of observations taken, others are a function of the amount of historical data that have been rescued and made available to the global community. The degree to which national archives have been digitised differs substantially. Furthermore, many digitization efforts have focused on the most widely-used parameters, e.g., temperature, often leaving out other parameters that are nevertheless of increasing interest. One such parameter is the occurrence of thunder, which can be used to extend lightning records back in time. Given the need for as much historical climate data as possible for the purposes of climate assessment, adaptation and mitigation planning, and reanalyses, this action aims at encouraging a renewed concerted effort to locate and rescue observations of particular interest that are available but have not yet been digitised and incorporated into existing archives.
Implementers	From 1 to 3: **Existing data rescue organizations**, WMO, GCOS, Funding agencies, NMHSs, National governments.
Means of Assessing Progress	1. Updates by NMHSs and others of data rescue inventories maintained by WMO DARE with newly discovered and as yet unregistered holdings. 2. New funded data rescue efforts leading to the provision of additional data rescued to recognized global repositories for relevant ECVs via a variety of approaches (professional keying, citizen science, participatory learning). 3. Updated best guidance documentation for data rescue activities readily available to support funded data rescue activities.
Additional Details	WMO Unified Data Policy includes sharing of historical data and should inform the planning and execution of the activities within this Action. It is important to rescue the raw data as well as the processed ECVs.
Links with other IP Actions	A successful D5 will provide datasets with historical observations feeding into global climate data centres considered in Actions D1-D3.

5. THEME E: ENGAGING WITH COUNTRIES

Many climate observations are made by national bodies, however these efforts need support and coordination. Some countries have national programmes that need to be connected regionally and globally to share and communicate issues and solutions. GCOS can help by linking these national efforts into the global system, providing information on observing needs, promoting needs for support and access to global information.

GCOS has started to engage at regional and national levels through a series of regional workshops. These have been paused due to COVID but need to be restarted and strengthened. Links to national observing systems should be put into place. Ultimately the benefits of climate observations need to be widely understood and the contributions of national observations to global datasets enhanced.

Some national GCOS systems can also fill gaps in the global system, for example by providing support for regional and global data centres.

Action E3: Enhance support for national climate observations	
Activities	**1. Identify additional sources of support for climate observations.** **2. Identify national needs for network support that will not be addressed by WMO's GBON and SOFF.** **3. Publicise these to potential donors and try to mobilise the resources needed.**
Issue/Benefits	In countries with limited resources, it is often difficult to maintain long-term systematic climate observations, due to competing priorities. The WMO GBON and SOFF have been established to address this need for climate and meteorological observations: however, there are many ECVs that will not be addressed via these mechanisms, for many years to come, if ever. The GCOS Cooperation Mechanism was established to assist countries in developing their climate observation capacity. In recent years donations to the GCM have been limited and it has focused on supporting radiosondes – this will now be covered by GBON and the SOFF. While the GCM should try to address other ECVs it should also return to its original concept: identifying national needs and international assistance available.
Implementers	From 1 to 3: **GCOS**, National governments, Funding agencies.
Means of Assessing Progress	1. List of additional donors. 2. List of national network support needs. 3. a) Increase in national network support; b) Funds raised by the GCM.
Additional Details	1. An inventory of potential donors should be established and maintained. Pro-actively engage with the potential donors to explore additional funding models/streams. 2. There are many needs for support to observations. Based on the regional workshops (E1) and national engagement (E2) as well as an understanding of the major gaps identified in the GCOS Status Report, a list of specific proposals to improve observing networks can be established. 3. Fundraising for the GCM should recommence. This will require clarity on how it will supplement the SOFF for climate observations, the benefits of the observations and how they provide global goods. In parallel, matching of countries to donors can also provide the required resources.
Links with other IP Actions	Actions E1 and E2.

6. THEME F: OTHER EMERGING NEEDS

As countries respond to the impacts of climate change, they need data related to the specific areas impacting their countries. Many impacts are directly related to extremes, for example heatwaves, flooding and droughts. While work continues to identify how the global system can support these national and local needs, some requirements are already evident. Many users will not use the observed data directly, but rather use reanalysis products. Observing in areas of interest, at relevant resolutions will greatly improve reanalysis. This theme addresses some of these needs ranging from higher resolution data (both spatial and temporal) to monitor extremes, to monitoring of areas of specific concern where impacts on humans are at their greatest: coastal and urban areas. Finally, there is a widespread interest in improving monitoring of GHGs fluxes to support national GHGs inventories and mitigation and to detect changes in the overall cycles of these gases. GCOS will continue to identify the needs of adaptation and supporting the Paris Agreement: this theme just addresses actions that have already been identified and can be started in the lifetime of this plan, 5-10 years.

Action F4: Improve climate monitoring in urban areas	
Activities	**1. Audit existing GCOS ECVs to identify those that are urban-relevant and produce updated requirements where needed.** **2. Identify new urban-relevant products and define their requirements.** **3. Develop plans to address the urban monitoring requirements identified in Activities 1 and 2.**
Issue/Benefits	The majority of the human population lives in cities and urban areas, including informal settlements, are primary locations for economic and social activity, and hence these are critical locations for emissions mitigation and climate adaptation. Effective monitoring of climate relevant parameters will therefore yield substantial benefits. Such climate relevant parameters include the normal meteorological observations, but also extend to observations of other relevant variables such as pollution emissions and land use and land cover (LULC). Traditional measurements of standard meteorological parameters have sought to eliminate urban influences, wherever possible, but the reality is that temperatures that are elevated by urban influence do actually represent the climatic conditions experienced by a large proportion of the global population and are especially important when considering adaptation to climate change. Sufficient standardized observations of these complex environments are required to understand the heterogeneity of urban climates, and this in turn is key to making informed adaptation decisions.
Implementers	From 1 to3: **GCOS**, WMO, Academia, National agencies, Research organizations, NMHS.
Means of Assessing Progress	1. GCOS Adaptation Task Team progress and final reports to GCOS Steering Committee. 2. Upgraded GCOS documentation (especially for TOPC and AOPC) to clearly identify existing, upgraded and new ECVs relevant to urban climate and adaptation. 3. Plans to address urban monitoring needs and updating the user requirements.
Additional Details	Processes and procedures are identified in the working documents produced by the GCOS Adaptation Task Team (GATT). Better monitoring in the urban area is also clearly needed to measure exposure to black-carbon, ozone and aerosol precursor emissions, NO_2. The enhancement of GCOS capability in these areas will additionally broaden GCOS engagement with stakeholders in both provision and use

	of the relevant observations. For example, enhancement of LULC capability for urban areas might require engagement with urban climate community and the World Urban Database and Planning Tool (WUDAPT).
Links with other IP Actions	B4: expansion of atmospheric composition observations. F5: Activity 4 – improve measurements of relevant ECVs om large cities.

Action F5: Develop an Integrated Operational Global GHG Monitoring System	
Activities	The overall aim here is to develop an integrated operational global greenhouse gas monitoring infrastructure. The first steps are: 1. Design and start to implement a comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations routinely exchanged in near-real time suitable for monitoring GHG fluxes. **2. Design a constellation of operational satellites to provide near-real time global coverage of CO_2 and CH_4 column observations (and profiles to the extent possible).** **3. Identify a set of global modelling centres that could assimilate surface and satellite-based observations to generate flux estimates.** **4. Improve and coordinate measurements of relevant ECVs at anthropogenic emissions hotspots (large cities, powerplants) to support emission monitoring and the validation of tropospheric measurements by satellites.**
Issue/Benefits	The Paris Agreement requests Parties to regularly provide estimates of anthropogenic emissions by sources and removals by sinks of greenhouse gases, and information necessary to track progress made in implementing and achieving their nationally determined contribution under Article 4. The proposed global greenhouse gas monitoring infrastructure would support the development of these estimates (i.e. emission inventories); validate national and regional achievement of Parties' commitments in their National Adaptation Plans (NAPs); and monitor changes to the cycles of GHG that may impact the achievement of the temperature goal of the Paris Agreement. Monitoring of hot-spots via dedicated observations to validate specific point-source emissions and identify missing sources form emission inventories. Remote monitoring of atmospheric composition can quantify and identify major emission sources. Anthropogenic emission hotspots like cities and industrial facilities and power plants contribute strongly to the global GHG emissions and to emission of key ozone and aerosol precursors (SO_2, VOCs). Reliable remote observations of these emission hotspots in synergy with source detection models can contribute to verifying emission estimates and monitor and guide mitigation efforts (link to Flux ECV).
Implementers	1. **WMO (INFCOM, GAW and IG3IS).** 2. **Space agencies**, National agencies, Research organizations, Academia. 3. **WMO (INFCOM, GAW and IG3IS)**, National agencies. 4. **GCOS,** Space agencies, National agencies.
Means of Assessing Progress	1. Expanded observations of GHGs, ozone and aerosol precursors, aerosols and aerosol profiles near hotspots. 2. Designs and plans for in situ and satellite observations. 3. Identification of global monitoring centres that run global Chemistry Transport Models.

	4. a) Improved satellite retrievals in the presence of varying aerosol loadings in urban and hotspot conditions. Improved uncertainty quantification of GHG retrievals in the presence of aerosols; b) Number of emission detection studies using in situ and satellite data near hot spots.
Additional Details	From 1 to 3: Based on an initial concept paper prepared by the WMO Secretariat entitled "A WMO-coordinated Global Greenhouse Gas Monitoring Infrastructure" and the Report from the WMO-hosted Greenhouse Gas Monitoring Workshop in May 2022, the 75th Session of the WMO Executive Council decided to proceed with the further development of the concept for a WMO-coordinated Global Greenhouse Gas Monitoring Infrastructure, building on existing WMO programmes and other regional or global infrastructure and initiatives. This infrastructure will consist of the following main elements: a) A comprehensive global set of surface-based observations of CO_2, CH_4 and N_2O concentrations routinely exchanged in near-real time; b) A constellation of satellites to provide near-real time global coverage of CO_2 and CH_4 column observations (and profiles to the extent possible); c) A global Chemistry Transport Model (CTM) driven by output from a high-resolution global NWP model; d) Operational near-real time assimilation of the GHG observations a) and b) into CTM and routine dissemination of the output. 4. Hot spots include urban areas, industrial zones and individual large plants. 4.1 Enhance observations in urban areas: a) Expand the network of GHG observations that measure around urban areas, in particular column and profile observations. These observations will support integration of satellite missions that detect and quantify sources; b) Ensure co-located observations of co-emitted gases (typically ozone and aerosol precursors) CO, NO_2, SO_2, VOCs. 4.2 Ensure co-located observations of aerosols loadings and aerosol profiles in urban areas: a) Improve satellite retrievals in emission hotspots; b) Evaluate GHG retrievals in urban areas by considering varying aerosol loadings using reference observations; c) Focus on improving GHG retrievals and their uncertainty quantification in urban and other local hotspot cites (Action B3). Present challenges in monitoring emission hotspots include: • Missing reference data sets of GHGs and other co-emitted gases and aerosols in urban areas. • Challenges in estimating GHG concentrations in the presence of varying aerosol loads. Underestimated (or overestimated) uncertainties can mislead the emission estimation. • Integration of in situ and satellite measurements. In the future, measuring stable isotopes of carbon will allow separation of natural and fossil sources of GHG.
Links with other IP Actions	B3: New satellite missions. B4: In situ monitoring of aerosols and greenhouse gases. F4: Climate monitoring in urban areas.

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